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A review on emissions and mitigation strategies for road transport in Malaysia

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ABSTRACT

The emissions from road transport are serious threats to urban air quality and global warming. The first step to develop effective policies is to determine the source and amount of emissions produced. This paper attempts to review emissions from road transport using COPERT 4 model and examined possible emission mitigation strategies. In road transport, results have show that passenger cars are the main cause of CO_2, N_2O and CO emissions, while motorcycles are main source of hydrocarbon (HC) emissions. However, light duty vehicles and heavy duty vehicles are the main contribution of particulate matters. The total CO_2 equivalent emissions for road transport in Malaysia are 59,383.51 ktonnes for year 2007. Further results show that CO_2 emission is the primary source of greenhouse gas pollution which is 71% of the total CO_2 equivalent. A parametric study was conducted to estimate the potential emission mitigation strategies for road transport by taking the emissions in 2007 as a reference year. It was observed that promoting the public transport is an effective strategy to reduce emissions and fuel consumption from the technical view point. It can totally save up to 1044 ktonnes of fuel consumption and total CO_2 equivalents emissions can be decreased by 7%. It was noted that, fleet renewal and promoting natural gas vehicles will significantly contribute in the reduction of emissions in Malaysia.

Contents

1. Introduction

The world today is faced with global warming and air pollution. There has been a growing concern recently about energy use and its adverse impact on the environment. Vital to today's globalized economy the transportation sector is the most significant sector that accelerates environmental degradation among other economic sectors [1]. The fact that the transport sector is growing quickly and providing some benefits such as quick access to any geographical location on the earth. However, it also brings disadvantages like noise, congestion and pollutant emissions such as

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Nomenclature

$\beta_{i,j}$	fraction of mileage driven with cold engines or catalyst operated below the light-off temperature
E_{TOTAL}	total emissions of any pollutant [g]
$e_{HOT;i,j,k}$	hot emission factor in for the pollutant i, of the vehicle category j, drive on roads of type k [g/km]
$e_{COLD}/e_{HOT\|i,j}$	ratio of cold over hot emission factor for pollutant i emissions, relevant to vehicles of category j
N_j	number of vehicles in vehicle category j [veh.]
$M_{j,k}$	mileage per vehicle driven on roads of type k by vehicles of category j [km/veh.]

carbon dioxide (CO_2), the greenhouse gas (GHG) which are primarily responsible for global warming [2,3]. CO_2 emissions generated by the transportation sector have been causing much concern among the community worldwide, due to its rapid growth rates and the fact that CO_2 is the main greenhouse gas [4]. At the moment, the transportation sector accounts for 13.5% of global warming [5]. The amount of CO_2 emitted from distance traveled is directly proportional to fuel economy with every liter of gasoline burned releases about 2.4 kg of CO_2 [6].

Transportation sector makes a vital contribution to the economy and plays a curial role on daily activities in Malaysia like many other developing countries. At the same time, transportation also becomes a significant source of air pollution and is currently one of the largest emission sources in megacities with subsequent adverse effects on human health in the 21st century [7]. It involves different modes of transportation such as road, rail, air and maritime. Each mode of transport has its own advantages, however road transport is a dominant mode of the transportation system and it covers 85.71% of total passengers [8]. The rail passengers are about 14.05% while air transport carries 0.24% of the total passengers. Although, road transport has the advantage of providing door-to-door transportation and convenience for our daily life, its fuel consumption and emissions per km traveled are much higher than other transport modes [9]. The emissions from road transport are serious threats to urban air quality and global warming [10]. Besides, the limited fuel supply such as petrol and diesel for road transport is another challenge to overcome.

The boosting of economy in Malaysia which recorded an average gross domestic product (GDP) growth of 6% over the last 20 years is one of the factors that aid this increase in motor vehicle ownership [11]. The number of road transport in Malaysia has reached a total of 16,813 thousand vehicles in year 2007 [12]. This strong motorization has caused increasing concerns on local and long-range air pollution. Therefore, in the recent past due to the development of global environmental issues, research and planning in urban transportation is biased towards the greenhouse gas mitigation strategies [13].

Determination of quantities of the pollutant emissions from the road transport sector is the first step to develop effective policies for solution of the problem. Emission inventory models such as COPERT, MOBILE and MVEI provide reliable estimates of road transport emission if sufficient reliable input data for the models can be provided [14–16]. These models can even be used in a predictive fashion for different scenarios so that policy-makers can make better decisions for the future. However, preparation of detailed statistical data for different vehicle categories and their specific operating conditions are challenges to be overcome [9]. These models are useful tools for policymakers especially for developing countries like Malaysia.

Table 1
Fuel consumption by road transport for the year 2007 [21].

Fuel type	Fuel consumption (ktoe*)
Petrol	8549
Diesel	4859
Natural gas	147
Total	13,555

* kilo tonnes of oil equivalent.

Road transport vehicles are commonly known as a significant contributor of atmospheric emission of numerous GHG including carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) [17]. Meanwhile, the quantity of CO_2 emitted from road transport is the main contribution to GHG [18]. The trend is upward for CO_2 emissions in Malaysia which account for 6.7 metric tonnes per capita in year 2006 [19]. The transport sector is the fastest growing source of greenhouse gases. Road transport also remains the main source of many local emissions include CO, NO_x, non-methane volatile organic compounds (NMVOC) and particulate matters (PM). The emissions of the local pollutants from road transport depend strongly on the fuel used, engine combustion technology, exhaust after treatment devices and vehicle operating conditions. Within urban areas the percentage of contributions due to road transport is particularly high. Emissions from road traffic are being substantially reduced by the introduction of new technologies, such as three-way catalysts and also by local traffic reduction measures. Nevertheless, the statistic shows an increase in road transport emission trends from 1990 due to an increase in fuel consumption and a growth in passenger car traffic and in car ownership per inhabitant [10].

It is important to note that the main issue concerning the emissions is the source–receptor relationship. Considering urban transport, the emissions are released where people live and the concentration is generally high enough to damage human health. Therefore, it is crucial for policy-makers to know the quantities and contribution of road transport emissions to ambient air quality in order to develop both technical and non-technical transport strategies to minimize human exposure to harmful emissions. Several research studies have been conducted on road transport ownership of developing countries including Malaysia and Thailand [20]. Most of these researches focused only on the ownership of passenger cars rather than other modes of road transport like motorcycle, public transport, etc. The main objective of this study is to estimate the quantities of road transport emissions in Malaysia. Besides, a parametric study was performed to determine the most effective road transport emission mitigation strategies such as passenger cars shift to public transports, motorcycles shift to public transports, passenger cars shift to natural gas vehicles and passenger cars renewal. All the technical results and emission effect for each potential strategy will be discussed in this study.

2. Data collection

The fuel consumption for road transport was collected from National Energy Balance's (NEB) annual report as shown in Table 1. It involved annual consumption of petrol, diesel and compressed natural gas for the road transport. Table 1 shows that petrol fuel involved more than 60% of the total fuel consumption for road transport in year 2007.

The final energy use in Malaysia has risen at a rate of 5.9% between 2000 and 2007 to 44.3 Mtoe in 2007 [21]. A huge portion of total energy is used in the transportation sector. This sector alone consumes 35.5% of the total energy consumption. Among all sectors the transport sector is the fastest growing energy consump-

Table 2
Road transport vehicle in Malaysia [12].

Year	Motorcycles	Cars	Buses	Taxi/hire cars	Goods vehicles	Other	Total	Growth rate (%)
1995	3,608,475	2,553,574	36,000	55,002	440,723	203,660	6,897,434	9.34
1996	3,951,931	2,885,536	38,965	59,456	512,165	237,631	7,685,684	11.43
1997	4,328,997	3,271,304	43,444	62,119	574,622	269,983	8,550,469	11.25
1998	4,692,183	3,452,852	45,643	64,632	599,149	286,898	9,141,357	6.91
1999	5,082,473	3,787,047	47,674	65,646	642,976	304,135	9,929,951	8.63
2000	5,356,604	4,145,982	48,662	66,585	665,284	315,687	10,598,804	6.74
2001	5,609,351	4,557,992	49,771	66,565	689,668	329,198	11,302,545	6.64
2002	5,842,617	5,001,273	51,158	68,139	713,148	345,604	12,021,939	6.36
2003	6,164,958	5,428,774	52,846	70,933	740,462	361,275	12,819,248	6.63
2004	6,572,366	5,911,752	54,997	75,669	772,218	377,835	13,764,837	7.38
2005	7,008,051	6,473,261	57,370	79,130	805,157	393,438	14,816,407	7.64
2006	7,458,128	6,941,996	59,991	82,047	836,579	411,991	15,790,732	6.58
2007	7,943,364	7,419,643	62,308	84,742	871,234	432,652	16,813,943	6.48

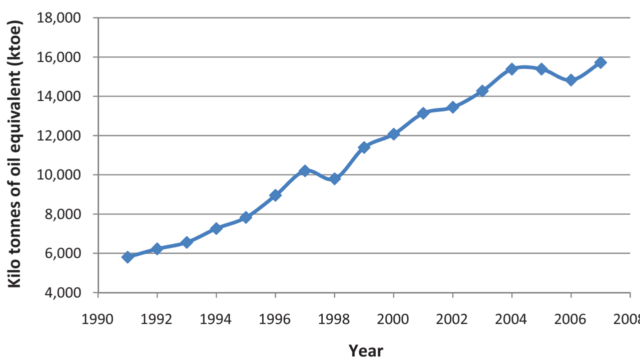

Fig. 1. Energy consumption by transportation sector in Malaysia.

Table 3
Average of ambient temperature in Malaysia [22].

Month	Minimum temperature (°C)	Maximum temperature (°C)
January	22	32
February	22	33
March	23	33
April	23	33
May	23	33
June	23	33
July	22	32
August	23	32
September	22	32
October	23	32
November	23	32
December	22	32

tion with an average rate of 6.2%. Fig. 1 shows the development of energy consumption by transportation sector from 1991 until 2007. The total energy consumption by transportation sector has recorded a total of 15,717 ktonnes oil equivalent in 2007.

The motor vehicle ownership has increased significantly every year and reached double of the number for every 10 years as shown in Table 2. The road transport vehicles have increased dramatically from 6.8 million vehicles in 1995 to 18 million vehicles in 2008 which is almost tripled with the annual growth rate of 7.78% from 1995 to 2008. The highest growth is in year 1996 and 1997 which are 11.43% and 11.25%, respectively.

The minimum and maximum ambient temperatures are needed to calculate the cold start emission. This data was collected from the department of statistic Malaysia [22]. The collected temperatures are based on monthly basis as shown in Table 3.

The European Union (EU) fuel regulation and emission standard EURO I were officially implemented in Malaysia from 1997 until 2000 for passenger cars, light duty vehicles and heavy duty vehicles. After that Malaysia homologated EURO II regulation standard

Table 4
Road transport speed limit for various roads [12].

	Default	Heavy duty vehicle	Urban and town area
Highways	110 km/h	80–90 km/h	80–90 km/h
Federal roads	90 km/h	70–80 km/h	60 km/h
State roads	90 km/h	70–80 km/h	60 km/h

for passenger cars and light duty vehicles since 2000. Yet, EURO II regulation standard was not implemented for heavy duty vehicles, therefore heavy duty vehicles still remain EURO I regulations until now.

The driving mode activity data and conditions affect the quantity of the exhaust emissions. The average speeds and average fleet mileage are used as the tuning parameters. The speed limit for road motor vehicles was collected from department of road transport as shown in Table 4. However, similar to other developing countries it is difficult to attain complete statistical and technical data. Estimates of the annual mileage of road vehicles are 19,320–20,000 km [23].

3. Methodology

The road transport emissions can hardly be measured in real world conditions and as a rule the emissions are calculated based on the traffic data and vehicle specific emission factors. These emission factors depend not only on the vehicle type but also to a large degree on the driving conditions and thereby can vary between different diving modes. Different methods exist for the determination of the vehicle emission factors, but the most common approach is based on the utilization of experimental data obtained from laboratory measurements performed on selected vehicles under different simulated driving conditions [24].

The first step to develop effective policies for road transport is to figure out the amount of emissions produced. One of the most extensive road transport emission modelling methods used within the European context is the COPERT (Computer Programme to estimate Emissions from Road Traffic) model [25]. COPERT is a mathematical model based on a large database including information on the national automotive fleet and several related parameters such as speed-dependent emission functions, fuel consumption, average speed and mileage for each vehicle categories (passenger cars, buses, trucks, etc.). Besides the basic emission factors, corrections are also provided accounting for cold starts and degradation of the emission reduction equipment with the age (mileage) of vehicles. COPERT 4 has been used to calculate emission of road transport in Malaysia for this study. It estimates the amount of greenhouse gas emissions such as CO_2, N_2O and CH_4 produced by different vehicle categories. Besides, it also calculates other major air pollutant emissions like CO, NO_x, NMVOC and PM.

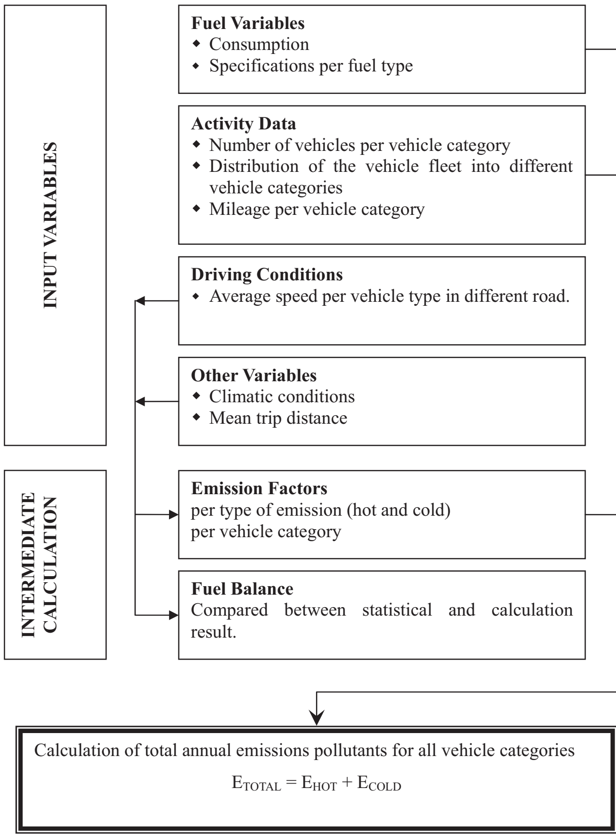

Fig. 2. Flow chart for the application of the baseline methodology [25].

Calculation of total emissions is made by combining activity data for each vehicle category with appropriate emission factors. Those emission factors vary according to input data like driving situations and climatic conditions. Also, information on fuel consumption and specifications are required to maintain a fuel balance between statistical input data and calculations. A summary of the variables required and the intermediate calculated values is given in the flow chart of Fig. 2.

3.1. Total emissions

In principle, total emissions are calculated by summing emissions from two different sources: Emissions produced during thermally stabilized engine operation (hot emissions) and emissions occurring during engine start from ambient temperature (cold-start and warming-up effects). In that respect, total emissions can be calculated by the following equation:

$$E_{\mathrm{TOTAL}} = E_{\mathrm{HOT}} + E_{\mathrm{COLD}} \tag{1}$$

3.2. Hot emissions

Hot emission is emission occurs under thermally stabilised engine and exhaust after treatment conditions. This emission depends on a variety of factors including the distance that each vehicle travels, the vehicle speed and an engine volume. Different emission factors for number of vehicles and mileage per vehicle need to be introduced in each vehicle category. COPERT 4 assumes that hot emission factors are dependent only on an average speed. Therefore, the formula to be applied for the calculation of hot emissions for the pollutants as below:

$$E_{\mathrm{HOT};i,j,k} = N_j \times M_{j,k} \times e_{\mathrm{HOT};i,j,k} \tag{2}$$

Table 5
Pollutant emissions in this study.

No.	Pollutants
1	Carbon monoxide (CO)
2	Nitrogen oxides (NO_x: NO and NO_2)
3	Methane (CH_4)
4	Volatile organic compounds (VOC)
5	Non methane VOC (NMVOC)
6	Particulate matter (PM)
7	Carbon dioxide (CO_2)
8	Nitrous oxide (N_2O)

3.3. Cold start emissions

Cold start emission take place under all three driving modes (urban, rural and highway). But, it seems to be most likely for urban driving. In principle it occurs for all vehicle categories. However, emission factors are only available or can be reasonably estimated for gasoline and diesel passenger cars. Therefore, assume that these other vehicles behave like passenger cars, so that all these categories are covered by the methodology. Moreover, cold start emission is considered not to be a function of vehicle age. These emissions are calculated as an extra emission over the emissions that would be expected if all vehicles were only operated with hot engines and warmed-up catalysts. A relevant factor corresponding to the ratio of cold over hot emissions is applied to the fraction of mileages driven with cold engines. The cold emissions are introduced as shown by using the following Equation:

$$E_{\mathrm{COLD};i,j} = \beta_{i,j} \times N_j \times M_j \times e_{\mathrm{HOT};i,j} \times \left[\left(\frac{e_{\mathrm{COLD}}}{e_{\mathrm{HOT}|i,j}} \right) - 1 \right] \tag{3}$$

The β parameter depends on ambient temperature and pattern of vehicle use in particular the average trip length (l_{trip}). However, since information on average trip length is not available for all vehicle classes, simplifications have been introduced for some vehicle categories. According to available statistical data, a value of 12.4 km has been established for the average trip length value [26]. Moreover, the mean trip length for total vehicle population can be considered as 17.2 km [27].

3.4. Emission under different driving mode

Vehicle emissions are heavily dependent on the engine operating conditions. Different driving situations impose different engine operating conditions and therefore a distinct emission performance. In that respect, a distinction is made in urban, rural and highway driving to account for variations in driving performance. Basically, cold start emissions are attributed to urban driving as the majority of vehicles starts any trip in urban areas. Therefore the emission pollutants can be displayed in different driving modes by following equation:

$$E_{\mathrm{TOTAL}} = E_{\mathrm{URBAN}} + E_{\mathrm{RURAL}} + E_{\mathrm{HIGHWAY}} \tag{5}$$

The data inputs require for the emission calculations in this study as shown below:

(i) Fuel consumption of road transport.
(ii) The maximum and minimum ambient temperature.
(iii) Fleet data (population of vehicles for each category).
(iv) Introduce of emission regulations in Malaysia.
(v) Mileage distribute and average vehicle speeds.

Once the data inputs are ready, COPERT 4 can be run to estimate the total emission for all categories of road transport on yearly basis. Table 5 shows the pollutant emissions calculated in this study and Table 6 shows the vehicle category [25,28].

Table 6
Detail of vehicle categories considered in the calculations.

Passenger cars	Light duty vehicles	Heavy duty vehicles	Buses	Motorcycles
Gasoline < 1.4 l	Gasoline < 3.5 t	Gasoline > 3.5 t	Diesel <= 15 t	2 stroke > 50 cm^3
Gasoline 1.4– 2.0 l	Diesel <3.5 t	Diesel < 7.5 t	Diesel 15–18 t	4 stroke <250 cm^3
Gasoline > 2.0 l		Diesel 7.5–16 t	Diesel >= 18 t	4 stroke >250 cm^3
NGV		Diesel 16–32 t		
Diesel < 2.0 l		Diesel > 32 t		
Diesel > 2.0 l				

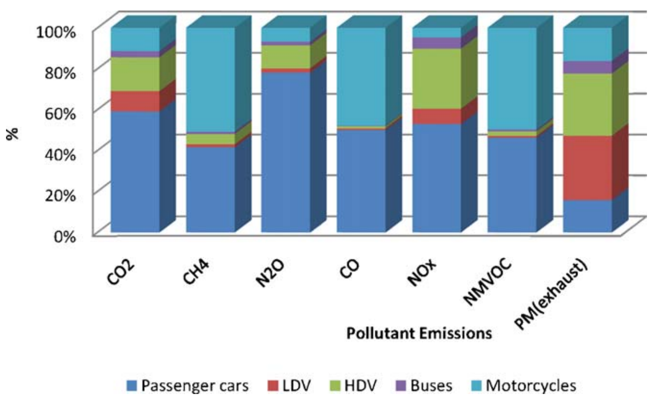

Fig. 3. Distribute of road transport emissions in 2007.

4. Results and discussion

4.1. Road transport emissions

The results of road transport emissions for the year 2007 are estimated by COPERT 4 and shown in Table 7. The results were indicated by the vehicle categories and driving modes of the pollutant emissions. The first three rows of the table shows the direct greenhouse gases pollutants CO_2, CH_4 and N_2O which is 42,157.96 ktonnes, 15.37 ktonnes and 1.66 ktonnes, respectively. Fig. 3 shows the distribution of road transport emissions in year 2007. Passenger cars are the main source for direct GHG pollutants which is around 59%, 42% and 78% of the total CO_2, CH_4 and N_2O emission respectively. Motorcycles are the major contribution of CH_4 emission which is 7.82 ktonnes and 51.9% of the total CH_4 emission. The other rows in Table 7 shows other emissions which are CO, NO_x, NMVOC and exhaust particulate matters. Passenger cars and motorcycles are the main cause of CO and NMVOC emissions. Besides, passenger cars also produced 157.67 ktonnes of NO_x and 1.8 ktonnes of particle matters. Light duty vehicles and heavy duty vehicles with diesel engine are the major contributors of PM exhaust emissions with a record 62% of total particulate matters exhaust.

The other pollutant gases like CO, NO_x and NMVOC do not contribute to radiative force but their presence affects the concentration of important components such as ozone. Therefore those gases are called indirect greenhouse gases. Table 8 displays the CO_2 equivalents of the gaseous emissions for those direct and indirect greenhouse gases with the global warming potentials (GWP) [29]. The CO_2 equivalents for the gas were calculated by multiplying the quantities of the gas with their GWP value. Table 8 indicates that the total of CO_2 equivalent emissions for road transports in Malaysia is 59,383.51 ktonnes. The CO_2 emission is the largest emitter of GHG which occupied 71% of the total CO_2 equivalents while followed by NO_x which accounts for 21%.

Table 8
CO_2 equivalent emissions (ktonnes).

GHG	Emissions	GWP	CO_2 equivalent	%
CO_2	42,157.96	1	42,157.96	71.0
CO	1769.51	2	3539.02	6.0
N_2O	1.66	320	531.65	0.9
CH_4	15.37	24.5	376.61	0.6
NO_x	298.30	40	11,931.97	20.1
NMVOC	211.58	4	846.31	1.4
Total			59,383.51	100.0

4.2. Emission mitigation strategies for road transport

Among many policies to reduce the air pollutant, it is important to identify the most realistic mitigation strategies that will able to meet GHG reduction goals. Emission inventory models can provide a cost effective means to study the various solutions of emission reduction strategies. COPERT 4 is a valuable tool to predict the response of the pollutant emissions and fuel economy to various road transport mitigation strategies. In this way, the most effective transport strategies can be determined and policies can be developed accordingly to optimize road transport. The road transport data and emissions in 2007 are taken as the reference to compare with four different transport strategies in this study. The four potential emission mitigation strategies are 10% of passenger cars shift to public transport, motorcycles shift to public transport, passenger cars shift to natural gas vehicles and vehicles renewal with Euro 4 emission standard. The 10% was chosen as a convenient figure for calculation to predict the response and effects of each potential mitigation strategies. Those results of the potential emission mitigation strategies were shown in Table 9.

4.2.1. Passenger cars shift to public transports

Passenger cars have the advantage of providing door-to-door and comfortable transportation but passenger cars emitted more

Table 7
Road transport emissions for year 2007 in Malaysia (ktonnes).

Emissions	Passenger cars	LDV	HDV	Buses	Motorcycles	Total
CO_2	24,852.67	4196.65	7000.97	1286.35	4821.32	42,157.96
CH_4	6.39	0.22	0.78	0.16	7.82	15.37
N_2O	1.30	0.03	0.19	0.03	0.11	1.66
CO	883.26	15.03	17.61	4.18	849.43	1769.51
NO_x	157.67	22.40	87.78	16.44	14.01	298.30
NMVOC	97.74	1.76	4.97	1.62	105.48	211.58
PM (exhaust)	1.80	3.61	3.49	0.71	1.86	11.46

Table 9
Results of potential emission mitigation strategies.

Parameters	CO_2	CO	NO_x	PM	HC	FC	Total CO_2 equivalent
Reference (Emission 2007)	100	100	100	100	100	100	100
10%* PCs shift to public transport	94.0	94.1	94.7	99.4	94.7	94.0	94.2
10%* motorcycles shift to public transport	99.1	94.7	100.2	95.4	86.3	98.3	98.8
10%* PCs shift to NGV	98.9	95.0	94.3	98.4	94.7	98.2	97.6
10%* PCs renewal	98.5	88.5	89.0	97.9	89.4	98.7	96.5

* 10% was chosen as a convenient figure.

pollutant and consume more fuel compare with public transport with the same passenger-km. Passenger cars generally have shorter trip lengths than public transport vehicles. Their trips frequently end before the engines and catalytic converters. Since cold-start emissions are significantly higher than for thermally stable engine operation, their reduction is a major concern for urban transport. Table 9 shows the results of substitution 10% of the oldest passenger cars with public transport while retaining the same passenger-km and data activities (10% was chosen as a convenient figure). As can be seen from Table 9, 10% shift of passenger cars has significantly reduced the pollutant emissions and fuel consumption. The CO_2 has reduced to 94% while NO_x and HC decreased to 94.7% from the reference year. Besides, it can save 6% of the total fuel consumption which is 813 ktonnes of oil equivalent. Furthermore, the total CO_2 equivalent and CO emissions have reduced 5.8% and 5.9%, but there is no significant change in PM emissions. The PM emissions have not changed because the high load public transport emitted more PM emissions per vehicle when compared to the passenger car. Public transport occupies less road space and causes less pollution per passenger-km than passenger cars. The results show that public transport is the potential solution for environmental pollution and road traffic. However, the average usage of public transport in the city is merely 16% in Malaysia. This is the lowest figure among the countries in Asia. Besides that the covering area of the rail line is not wide enough and therefore only minority passengers are accessible to it. Therefore, government should improve the infrastructure of public transport and promote it for wider usage to meet the goal of harmful gases reduction.

4.2.2. Motorcycles shift to public transports

Most of the older motorcycles are powered by two stroke engines. These engines have low scavenging efficiency due to the nature of the two stroke engine cycle. The fuel mixture of the two stroke engine are poorly utilized, hence some of the mixture leaves the combustion chamber through the exhaust without being burnt or combusted. The uncompleted combustion causes more harmful gases expulsed by the engine. Therefore, motorcycles are emitted large portion of CO, HC and PM emissions. The HC and PM emission factor for motorcycles are much higher when compared to passenger cars. Therefore, by reducing the usage of motorcycle it can decreases the CO and HC emissions. Table 9 shows the effects of 10% motorcycles change to public transport while remaining the same data activity and passenger-km (10% was chosen as a convenient figure). The results show that there is a significant reduction CO, PM and HC emissions to 94.7%, 95.4% and 86.3%, respectively from the reference year. On the other hand, there are no significant changes in CO_2 and NO_x emissions. The NO_x and CO_2 emission are not changed while the HC and CO emission are reduced in the sharp amount. This is because the diesel engine of public transport vehicles operates at relatively high load conditions and thus emits more NO_x, less HC and CO emissions compared to motorcycles. Besides, the total CO_2 equivalent also decreased to 98.8% by shifting 10% of motorcycles to public transport. As can be seen from above, the shift of motorcycle to public transport is an effective strategy to reduce the HC and CO emissions.

4.2.3. Passenger cars shift to natural gas vehicles

The usage of petrol and diesel for transportation sector have increased tremendously and caused Malaysian oil reserve to decrease rapidly over the past decade. Compressed natural gas (CNG) has become a promising alternative fuel for road transport. Compressed natural gas is a fossil fuel comprised mostly of methane and is cleaner burning than gasoline or diesel fuel. A comparative analysis of the performance and emissions show that CNG fuel has lower brake mean effective pressure (BMEP), brake specific fuel consumptions (BSFC), higher efficiency and lower emissions of CO, CO_2, HC but more NO_x compared to gasoline [30]. CNG is being considered as a practical alternative for the market and the environmental. The results of 10% passenger cars replaced with compressed natural gas fuel vehicles are shown in Table 9 (10% was chosen as a convenient figure). The total CO_2 equivalent decreased to 97.6% and fuel consumption to 98.2%. But there are not significant changes in CO_2 and particulate matters emission. However, the CO, NO_x and HC emissions have decreased 5%, 5.7% and 5.3%, respectively. This means that by using compressed natural gas as substitution transportation fuel can reduce the pollutant emission emitted by passenger cars. Natural gas vehicles (NGV) are a potential solution to oil shortages, global warming and air pollution. But there are very little natural gas consumption currently used as transportation fuel in Malaysia.

4.2.4. Passenger cars renewal

In addition to alternative fuels improvements in vehicle, the fuel economy on average mileage traveled by a vehicle per liter of fuel can significantly offset the amount of petroleum used in cars and trucks. There are quite a number of passenger cars that are more than 20 years old and still on the road today. Those cars have obsolete engines which have high emission level and not fuel efficient. However, the car today has latest engine technologies equipped with precision engine control unit, exhaust gas recirculation and air fuel ratio control unit. The test limits of EURO III are about 30–40% lower when compared to EURO II for diesel passenger cars and light commercial vehicles, there is a further drop about 30% for EURO 4 [31]. Therefore, it is beneficial to find out the effect of fuel consumption and emissions of older vehicle renewal. In this case, 10% of the oldest passenger cars were replaced with PC-EURO 4 vehicles with the same driving and transport activities (10% was chosen as a convenient figure). From Table 9 it shows that with a 10% of oldest cars renewal the total CO_2 equivalent can be reduced to 96.5%. Furthermore, there are significant reduced of CO, NO_x and HC emissions to 88.5%, 89% and 89.4%, respectively, and can save 1.3% of the total fuel consumption. The older cars usually have carburetor engine with poor air fuel control. Those cars generally operate at rich mixture and hence consume excessive amount of fuel and produce a mass of emissions. On the other hand, the cars with EURO 4 emission standard have catalytic converter which is very in effective on reducing the harmful emission especially NO_x. Besides, those cars have sophisticated engine technologies and engine control system for air fuel control, ignition and exhaust gas recirculation system which make up the car air fuel stoichiometry condition. Therefore, the fuel consumption and harmful emissions exhaust have

also reduced conjunctively. Obviously, it is shown that replacement the ancient passenger cars with the PC-EURO 4 cars have positive results in terms of fuel consumption efficient and reduction of pollutant emissions. Inspection and maintenance are regarded as essential to ensure that emission levels of vehicles do not exceed the acceptable levels.

5. Conclusion

The quantities of the road transport emissions in Malaysia were estimated using COPERT 4. Besides, parametric study of emission mitigation strategies was figured out by taking road transport data and emissions in 2007 as the reference. The following conclusions can be drawn from this study:

Total CO_2 equivalent emissions for road transport in Malaysia are 59,383.51 ktonnes. The CO_2 is the main source of GHG pollution which is 71% of the total CO_2 equivalent emissions, followed by NO_x at 21%. Passenger cars are the main cause of direct GHG pollutants. Besides, passenger cars are also major contributor of CO, NO_x and NMVOC. Nevertheless, light duty vehicles and heavy duty vehicles are the main responsible for exhaust PM emissions.

By replacing passenger cars with public transports, it can reduce the pollutant emissions and fuel consumption efficiently. A 10% of passenger cars replacement with public transports can decrease 6% of fuel consumption and CO_2. Furthermore, CO, NO_x and HC can be reduced to 94.1%, 94.7% and 94.7%, respectively. Therefore, a shift to public transports is a solution to environmental pollution.

Motorcycle is the largest share of the road transport that has dominated 47% of total road transport vehicles. Shifting motorcycle to public transport is an effective strategy for reduction of CO and HC emissions. The CO and HC emissions have reduced to 94.7% and 86.3% while there are no significant variations in CO_2 and NO_x emission.

Natural gas vehicles (NGV) will provide a solution to oil shortages, global warming and air pollution. A 10% of passenger cars substitution with compressed natural gas vehicles can decrease the CO, NO_x and HC emissions 5%, 5.7% and 5.3%, respectively. The total CO_2 equivalent has reduced to 97.6% and fuel consumption to 98.2%. However, no significant changes in CO_2 and PM emissions were observed.

Passenger cars renewal is one of the effective emission mitigation strategies to reduce the road transport emission in Malaysia. With renewal of 10% in the oldest cars, the CO, NO_x and HC emissions can be reduced to 88.5%, 89% and 89.4%, respectively from the baseline. Furthermore, it can save 1.3% of fuel consumption and total CO_2 equivalents emissions decrease 3.5%.

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